DE LA RECHERCHE À L'INDUSTRIE

cea

Galactica : a new astrophysical simulation open database

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AstroSim - Highlights and prospects for numerical astrophysics in France,
8-11 Octobre,2018 – ENS Lyon.

www.cea.fr

http://irfu.cea.fr/Projets/COAST

Outline

Astrophysical simulation database review

- Motivation
- Existing databases

The “Galactica” database, Terminus & Horus

- Introduction
- Architecture and Distributed data processing
- Editorial management
- Preview and web technology integration
- On-demand distributed data job requests (Terminus)
- Horus : scientific study graphic user interface (GUI)

1. Astrophysical simulation database short review

Why an astrophysical simulation database ? (1)

Astronomy : data reusability is a reality

- Astronomers apply for telescope time.
- They only get the exclusivity on the data for a brief period of time.
- After the public release : more science by other astronomers.

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Reusability of massive simulation data

- Astrophysical simulations produce ever-increasing volume of data.
- Growing cost for society to provide HPC resources (economical context).
- Reusability, a key requirement from :
  - Funding agencies,
  - HPC resource allocation commitees.
- Main concern : maximize scientific impact (with limited HPC resources).

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Main drags on simulation data mutualization

- Numerical solver and physical model implementation diversity,
- Great diversity of HPC architectures,
- Non-standardization of simulation data formats.

Existing databases in astrophysics

Massive cosmological or turbulence simulation databases

- Millenium simulation (Virgo consortium)

Virgo - Millennium Database

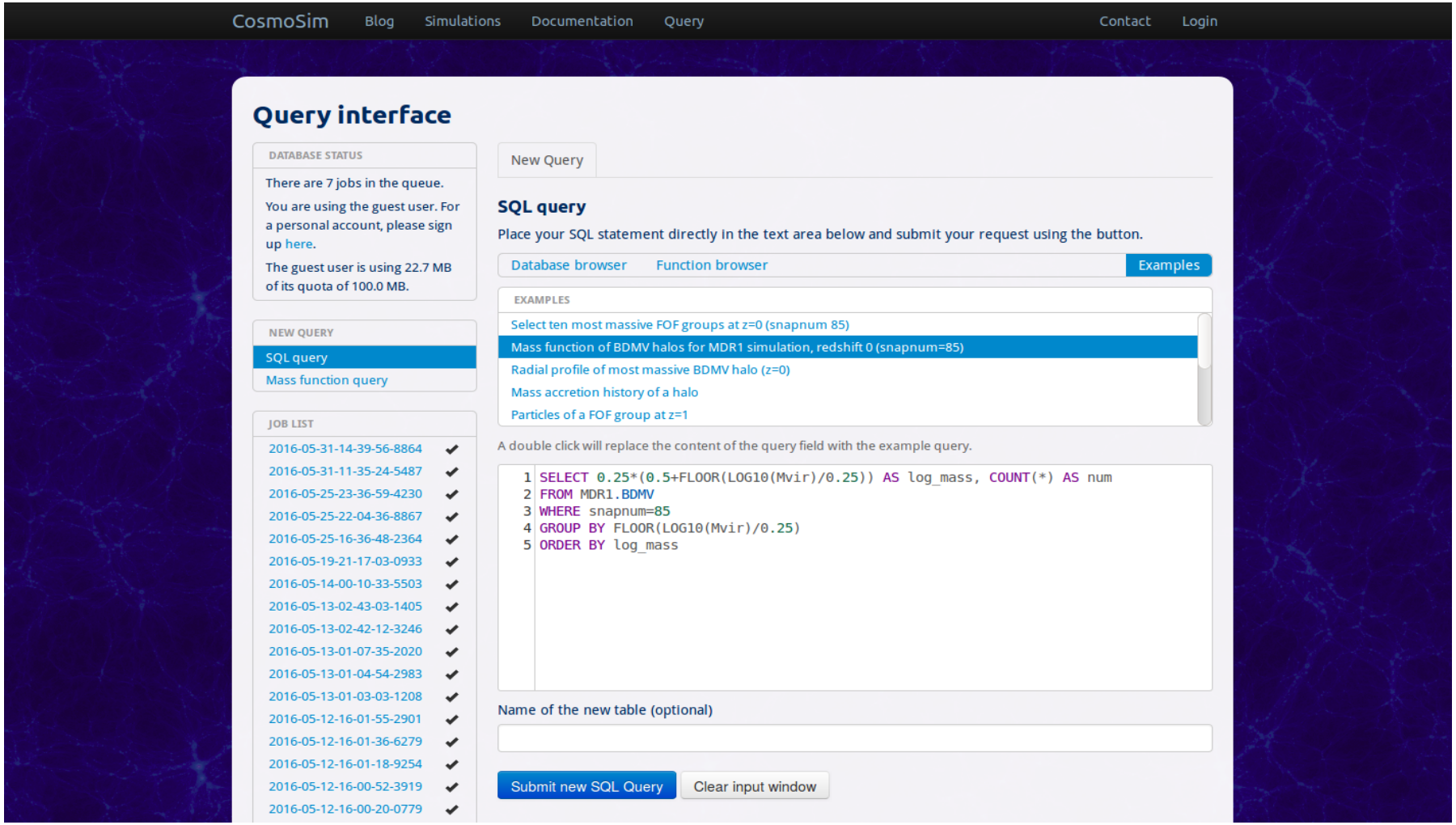
  - Online SQL query form only.
- CosmoSim (www.cosmosim.org)
  - Multiple cosmological simulations

MultiDark Bolshoi CLUES Constrained Local UniverSe Simulations

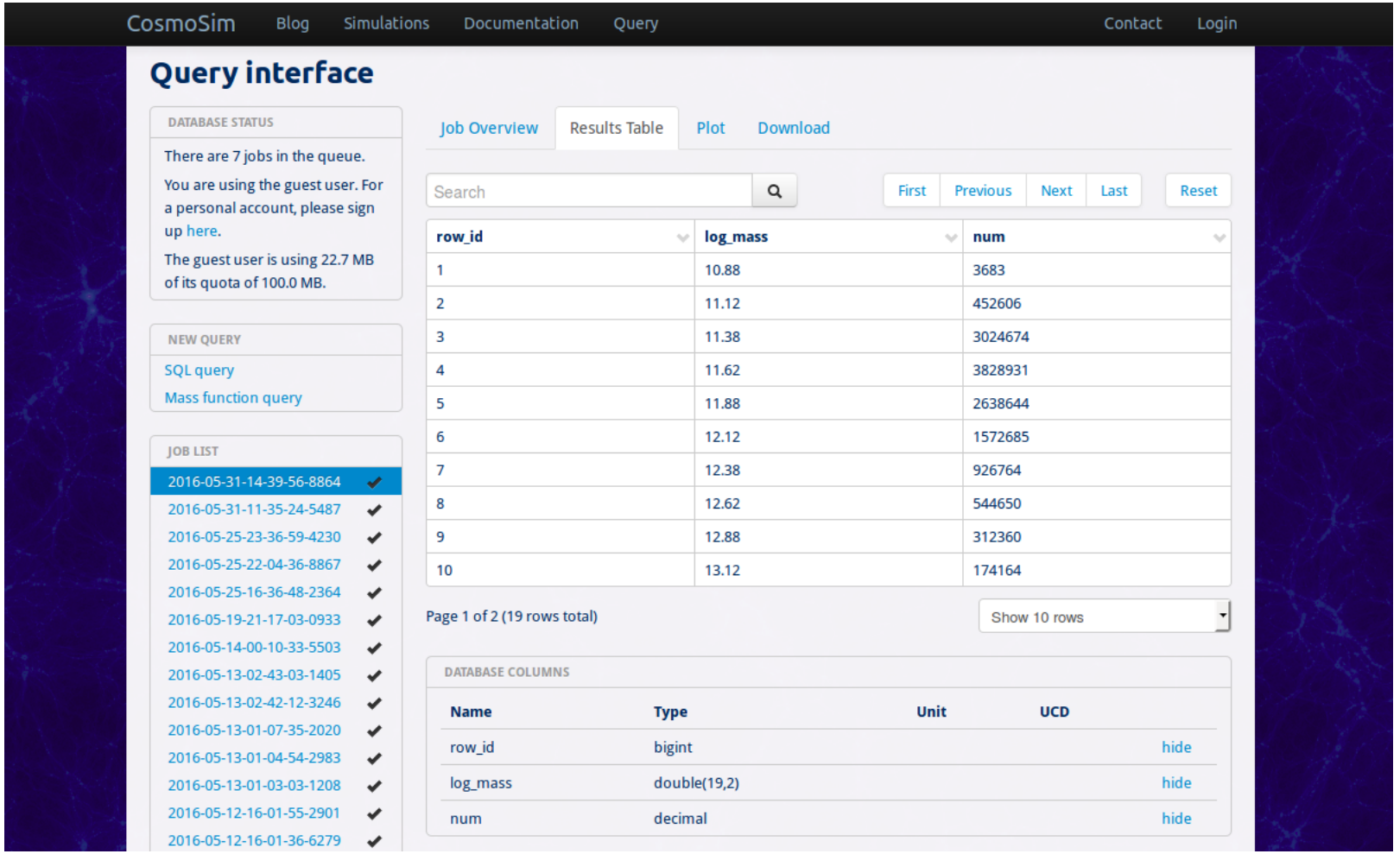
  - Use the Daiquiri framework (https://escience.aip.de/daiquiri) scientific database publication framework

  - Data access through :
    - Online SQL query form (+ plot and export tools).
    - SQL scripting (UWS client).
- CosmoHub : massive cosmological simulation analysis (https://cosmohub.pic.es)
- John Hopkins Turbulence Databases (http://turbulence.pha.jhu.edu)

Daiquiri: scientific database framework



Daiquiri: search result tables & plotting

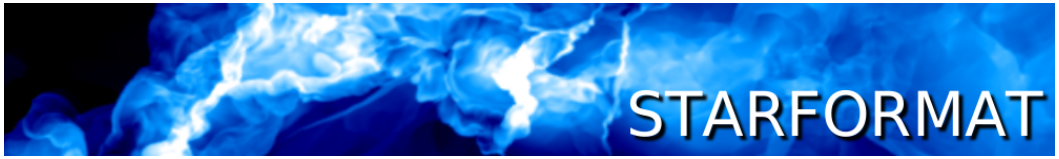


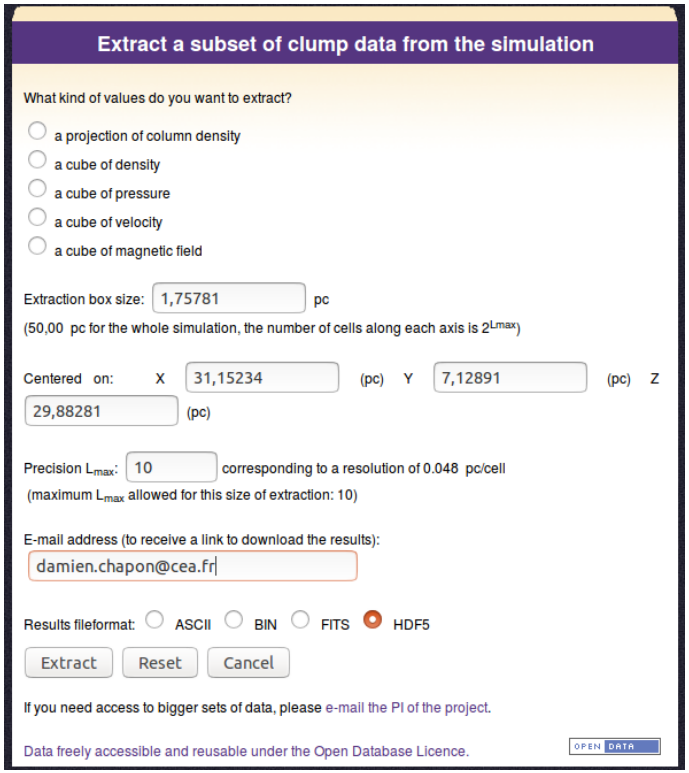
- Statistical approach to data access

V1.0 : StarFormat

StarFormat (Observatoire de Paris-Meudon)

- Molecular cloud formation/evolution/collapse simulation database,
- ~~Online SQL query form~~
- ~~Data acess web API,~~
- Downloadable content.
- Cloud selection form,
- On-demand post-processing services.





The Illustris project (cosmology)

The Illustris project (www.illustris-project.org)

- Data access REST API (Python/Matlab/IDL scripting)
- Downloadable media + raw data access
- Dark matter halo catalog search form.

Public Data Access Overview / Subhalo Search

You can search on min/max ranges for one or more Subhalo fields. When you select a field, the minimum, mean, and maximum at this snapshot are calculated for reference. The icons on each row link to: full details in the browsable API (spyglass), merger tree visualization (tree), galaxy stellar images (picture), snapshot extraction (download arrow).

1. Select simulation: Illustris-3 **and snapshot:** 135 (z=0) **or enter snapshot number:** 0 to 135

2. Select search fields and enter bounds:

Field	>=	<=	min	mean	max
mass	10.0	20.0	0.131521	10.5845	25250.1

Add Search Field

Search

ID	$M_{\rm tot}$ $[10^{10}M_\odot/h]$	$M_{\rm tot}$ $[\log M_\odot]$	$M_\star$ $[10^{10}M_\odot/h]$	$M_{\rm gas}$ $[10^{10}M_\odot/h]$	$M_{\rm DM}$ $[10^{10}M_\odot/h]$	x $[{\rm ckpc}/h]$	y $[{\rm ckpc}/h]$	z $[{\rm ckpc}/h]$	$r_{1/2}$ $[{\rm ckpc}/h]$	SFR $[M_\odot/{\rm yr}]$	$Z_\star(2r_{1/2,\star})$ –	$Z_{\rm gas}(2r_{1/2,\star})$ –	$v_{\rm max}$ $[{\rm km/s}]$	σ_v $[{\rm km/s}]$	m_U [mag]	m_B [mag]	m_R [mag]
0	25300.0	14.55	162.0	3070.0	22000.0	900.4	26286.7	18321.9	675.6	4.1110	0.0224	0.00635	896.9	543.8	-23.67	-24.06	-25.26
1	2470.0	13.54	33.0	40.3	2390.0	181.1	24638.8	16896.9	336.5	1.8752	0.0273	0.0601	399.3	262.1	-22.04	-22.45	-23.64
2	406.0	12.76	18.8	0.771	386.0	826.9	26747.3	17363.4	57.2	0.3440	0.0194	0.027	393.6	243.4	-21.08	-21.53	-22.77
3	310.0	12.64	11.3	4.49	294.0	1492.2	26514.9	19381.7	77.9	4.0408	0.0259	0.0309	306.7	172.9	-21.46	-21.66	-22.67

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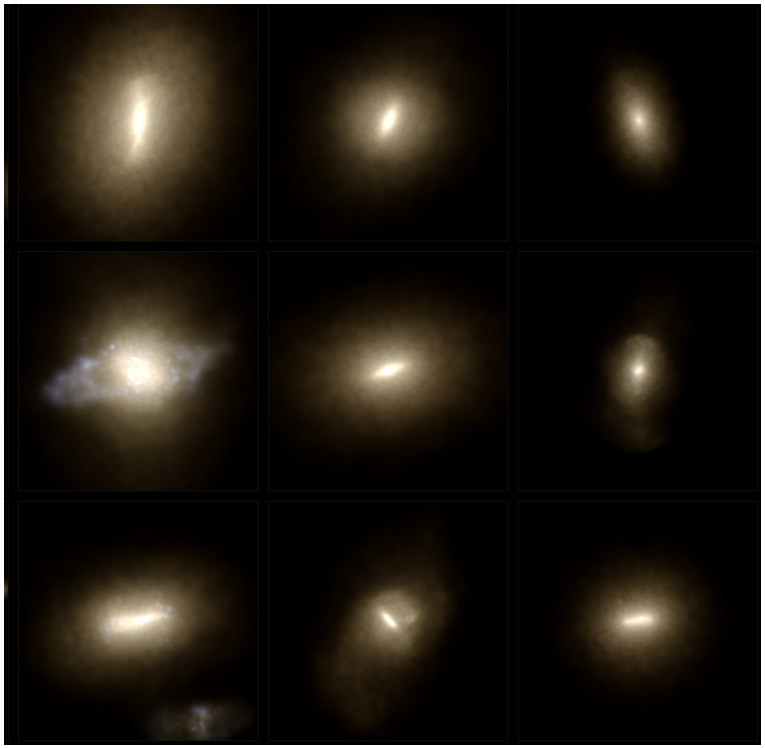

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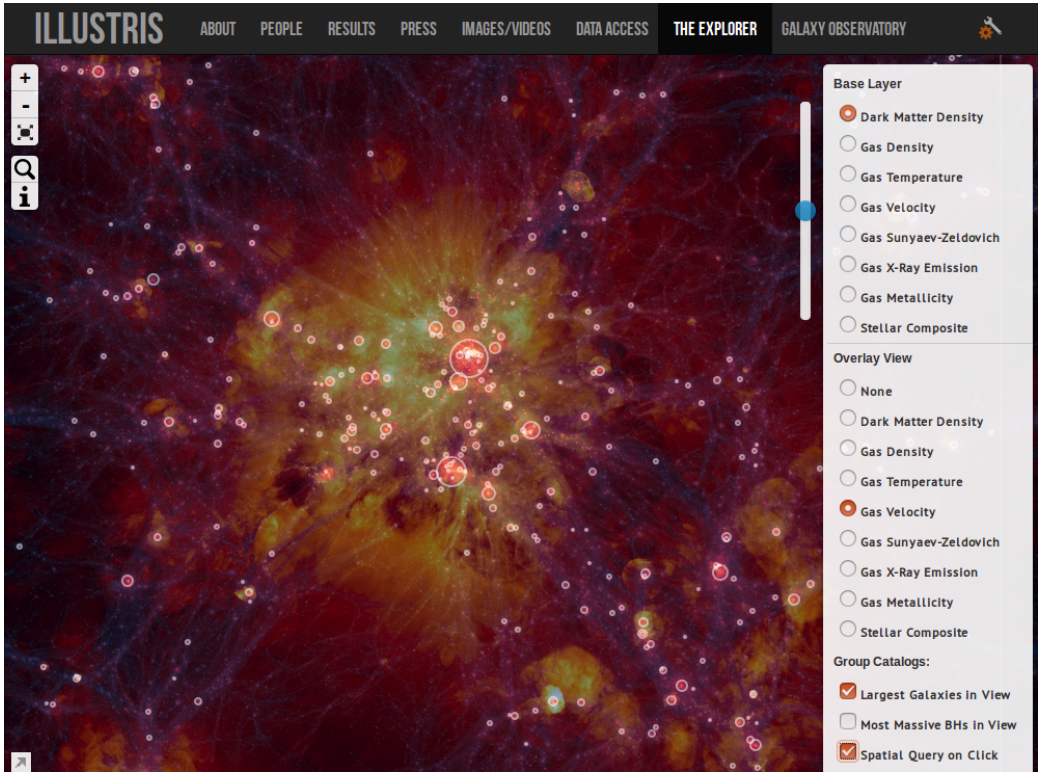
- Simulation explorer and visualisation tools :
  - Halo merger tree.
  - Particle extraction form.
  - Multi-layer 2D maps



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- Simulation explorer and visualisation tools :
  - Halo merger tree.
  - Particle extraction form
  - Multi-layer 2D maps
  - 3D simulation explorer (Illustris-TNG) with WebGL
    - Single cosmological project,
    - Static content,
    - Statistical approach, restricted to cosmology.

Why an astrophysical simulation database ? (2)

Multi-domain and multi-simulation platform

- COAST group research fields:
  - Cosmology, galaxy evolution and interactions,
  - Solar MHD, stellar dynamics, supernovæ explosions
  - Accretion disks, ISM, turbulence, star formation,
  - Planet formation, star-planet interactions, planetary atmospheres.

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Share data with scientific collaborators (first, then the rest of the world...)

- Most information cannot be included in a publication :
  - Complete code configuration (for reproductibility),
  - Dynamical evolution, interactivity with the data (search form, graphic user interface).
- Share reduced data and provide access to raw data :
  - Pre-processes downloadable content (images, plots, movies, ….),
  - « On-demand » post-processing online tools / job queue management (analysis + visualization)
- Collaborative work : online pre-publication platform ?

2. The « Galactica » database and « Terminus » data processing servers

Cross-domain multi-numerical project open database

- Generic simulation database (Solar MHD / star-planet interactions / ISM / Supernovæ explosions / Star formation / Galaxy evolution and interactions / Cosmology),
- Scientific pre-publication collaborative platform,
- **Open data** free to re-use and redistribute,
- Web application framework:
  - http://djangoproject.com.

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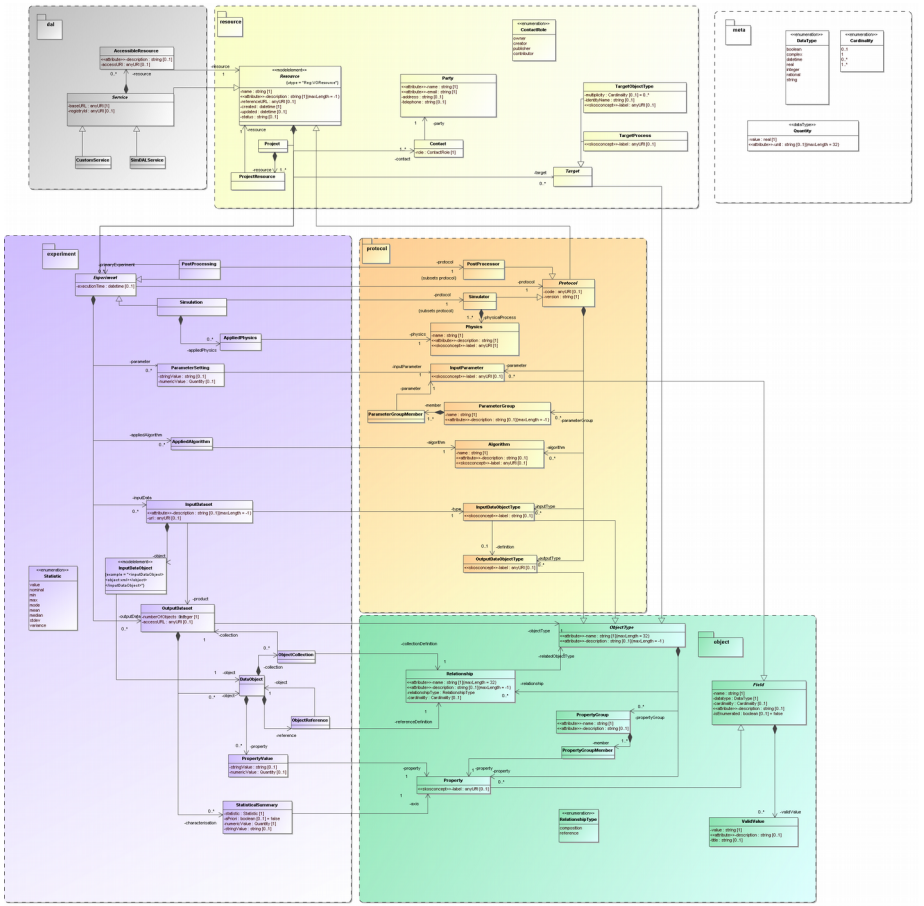
- Based on the **SimDM** IVOA standard :
  - https://ivoa.net/documents/SimDM.



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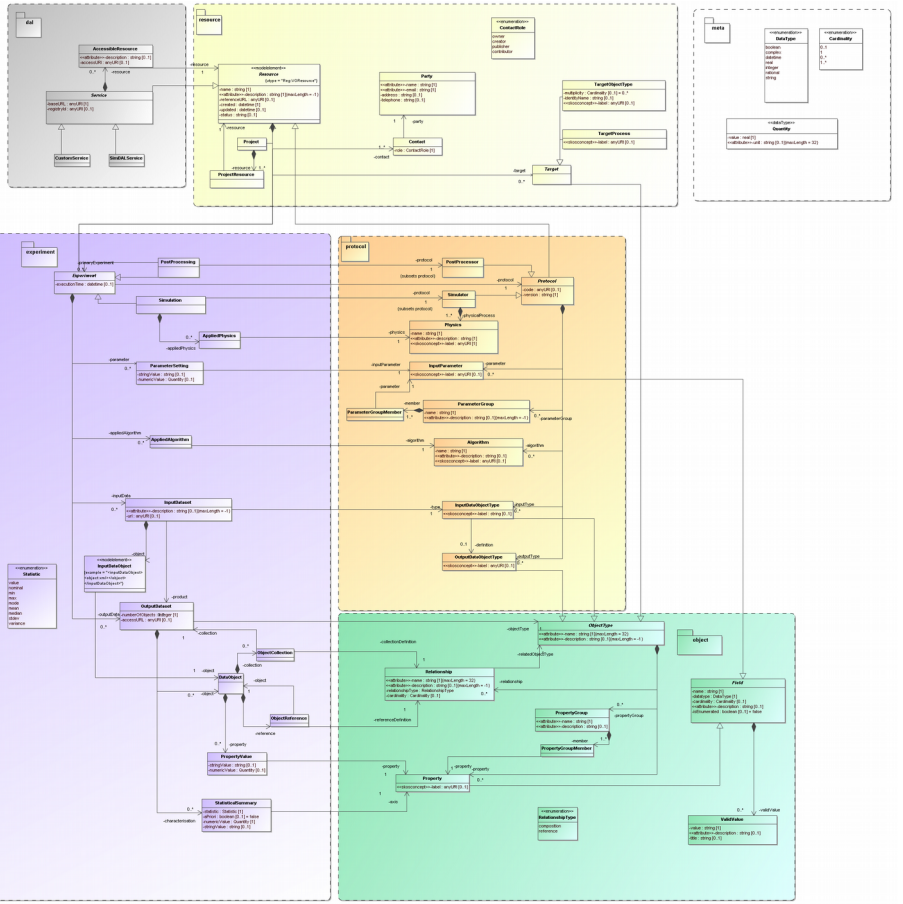
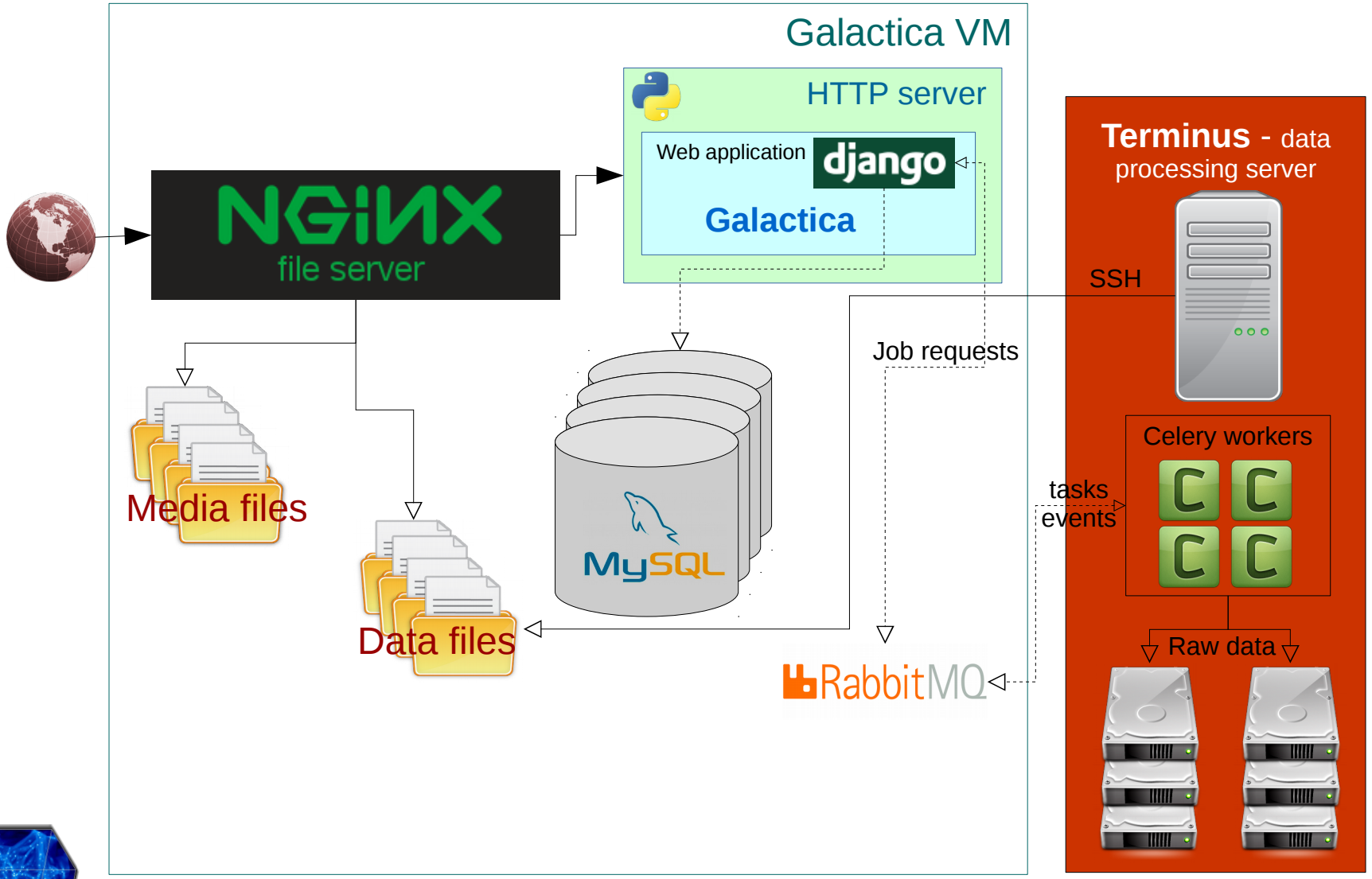
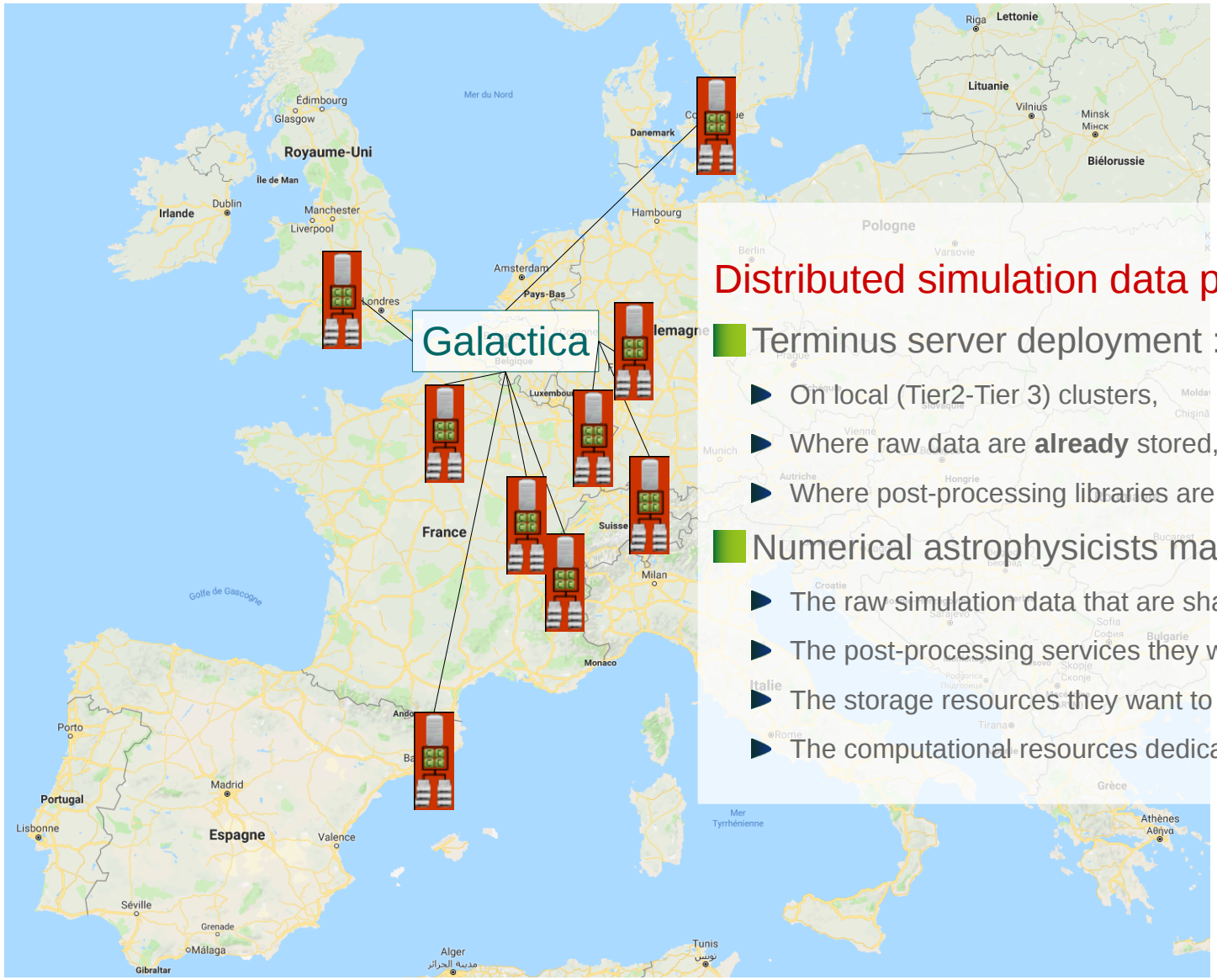
- Scientific pre-publication collaborative platform,
- **Open data** free to re-use and redistribute,
- Web application framework: django
  - http://djangoproject.com.
- Based on the **SimDM** IVOA standard :
  - https://ivoa.net/documents/SimDM.
- Terminus : async. data processing server
  - Celery async. tasks
  - e.g with a SLURM job queue management
  - Comm. : RabbitMQ message broker



Galactica web application architecture



Galactica & Terminus – distributed data processing

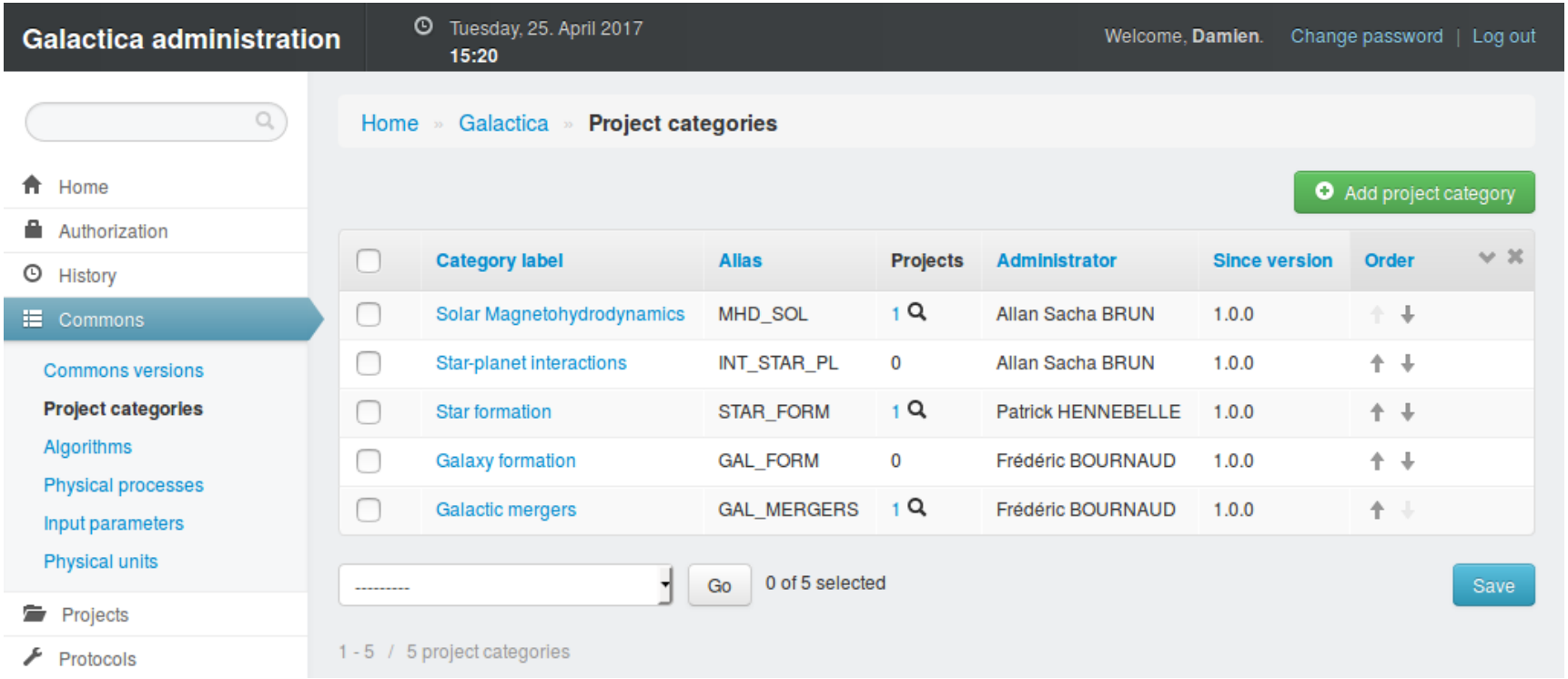


Distributed simulation data processing

- Terminus server deployment :
  - On local (Tier2-Tier 3) clusters,
  - Where raw data are **already** stored, no transfer needed,
  - Where post-processing libraries are **already** deployed.
- Numerical astrophysicists manage
  - The raw simulation data that are shared,
  - The post-processing services they want to provide,
  - The storage resources they want to allocate,
  - The computational resources dedicated to Galactica.

Administration user interface (django-suit)

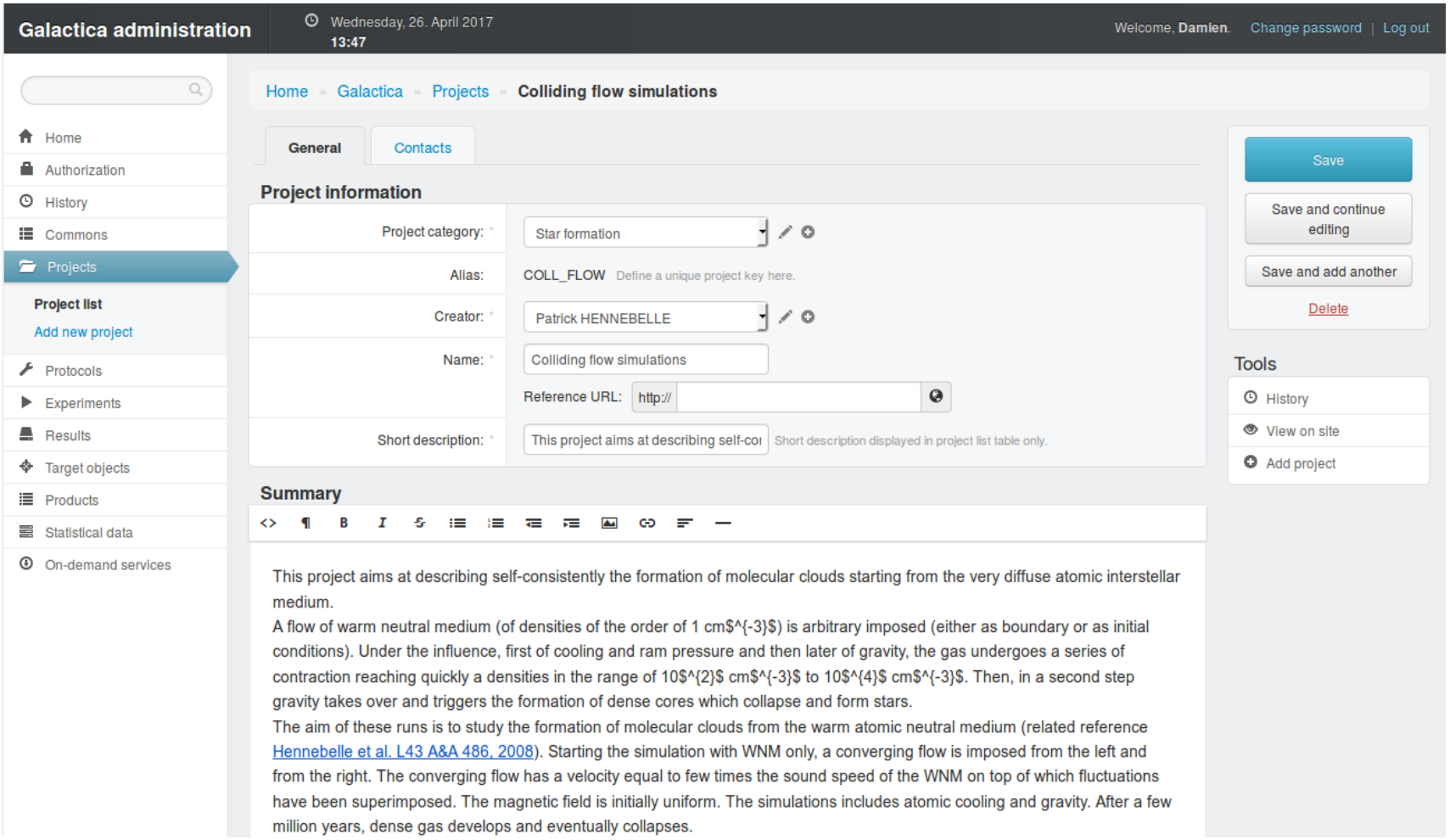
- Content management system (CMS) to edit (for authenticated ‘editor’ users only) :
  - Numerical Project pages,
  - Simulation runs, associated to simulation codes, and configuration parameters.
  - Results and their associated Datafiles,
  - Object catalogs (tabulated data), statistical data and their associated Datafiles.



Editorial management – project summary

Administration user interface (django-suit)

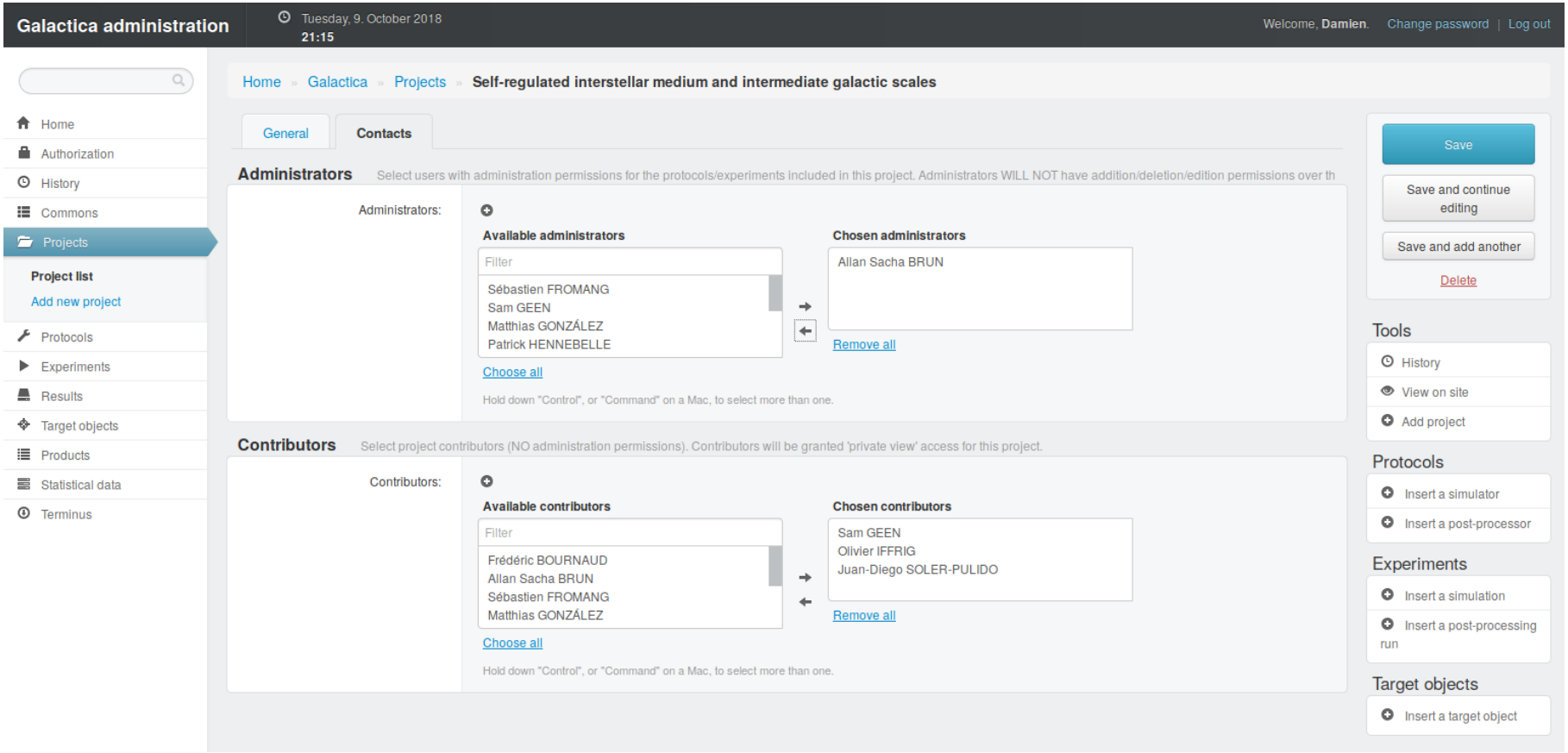
Project page edition



Editorial management – user permissions

Administration user interface (django-suit)

Project page edition – user permissions (read/write)



Editorial management – protocol page

Administration user interface (django-suit)

Protocol page edition

Galactica administration — Tuesday, 9. October 2018 21:21 — Welcome, **Damien**. Change password | Log out

Home » Galactica » Simulators » **RAMSES-MHD**

- Home
- Authorization
- History
- Commons
- Projects
- Protocols
  - **Simulators**
  - Post-processors
- Experiments
- Results
- Target objects
- Products
- Statistical data
- Terminus

General | Input parameters | Physics and algorithms

Save | Save and continue editing | Save and add another | Delete

Simulator information

Alias:	RAMSES_MHD Define a unique protocol key here.
Creator: *	Patrick HENNEBELLE
Project:	Self-regulated interstellar medium and intermediate galactic scales
Name: *	RAMSES-MHD — Reference URL: http:// http://www.ics.uzh.ch/~teyssier/ramses

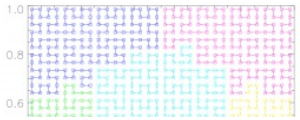
Protocol

Code: *	RAMSES — Version: * 3.0.0

Summary

RAMSES was developed in Saclay to study large scale structure and galaxy formation. It is now a rather flexible package to be used for general purpose simulations in self-gravitating fluid dynamics.
It is written in Fortran 90 with extensive use of the MPI library. It is a free software for non-commercial use only.
This code is a grid-based hydro solver with adaptive mesh refinement. As opposed to *patch-based AMR*, cells are refined on a cell by cell basis: is therefore called a **tree-based AMR**.
A very simple interface based on *Fortran namelist* can be used to specify runtime parameters.
A few routines can be modified to set more complex initial or boundary conditions.

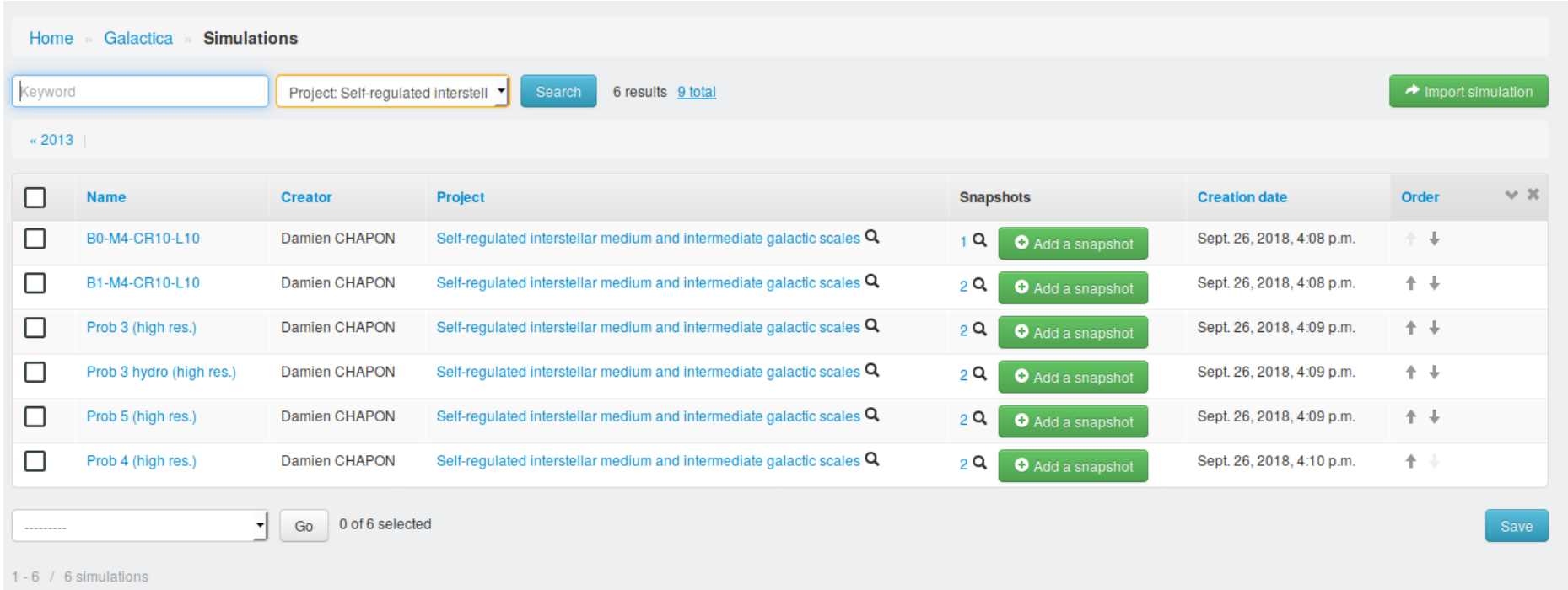
Tools
- History
- View on site



Editorial management – project simulation list

Administration user interface (django-suit)

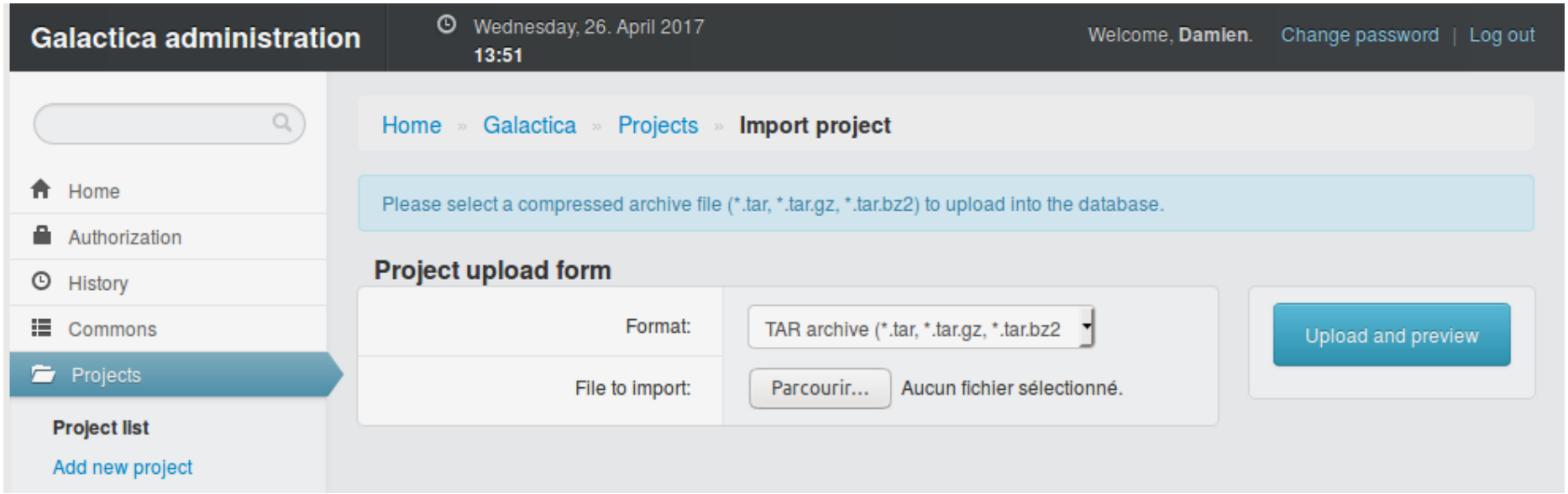
- Simulation list for a given project



Massive data import from Horus

Data import from « Galactica archive » files

- Example : project import
  - **Horus** exported file upload (*.tar.gz containing JSON metadata + attached datafiles),



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- Example : project import
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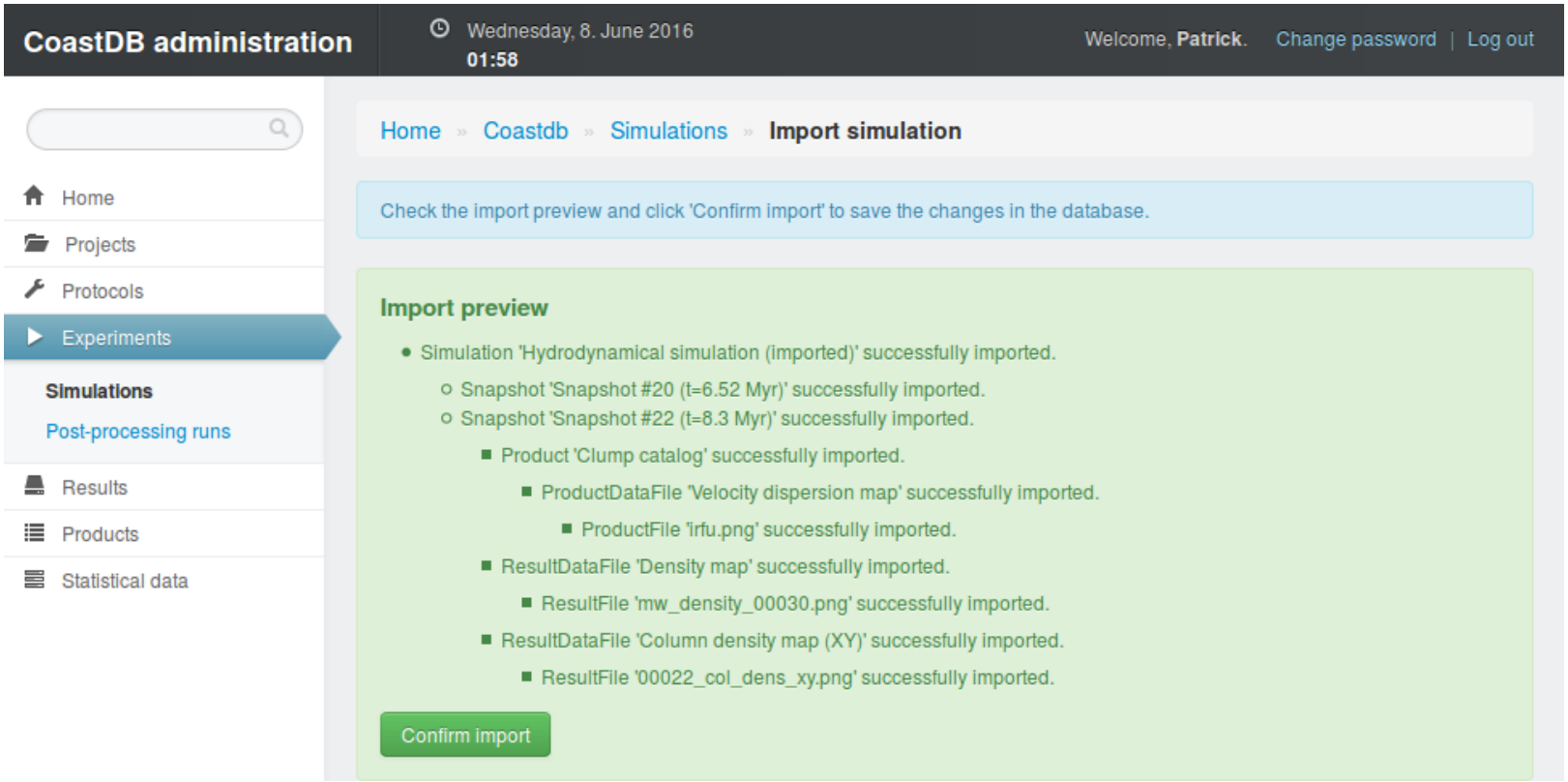
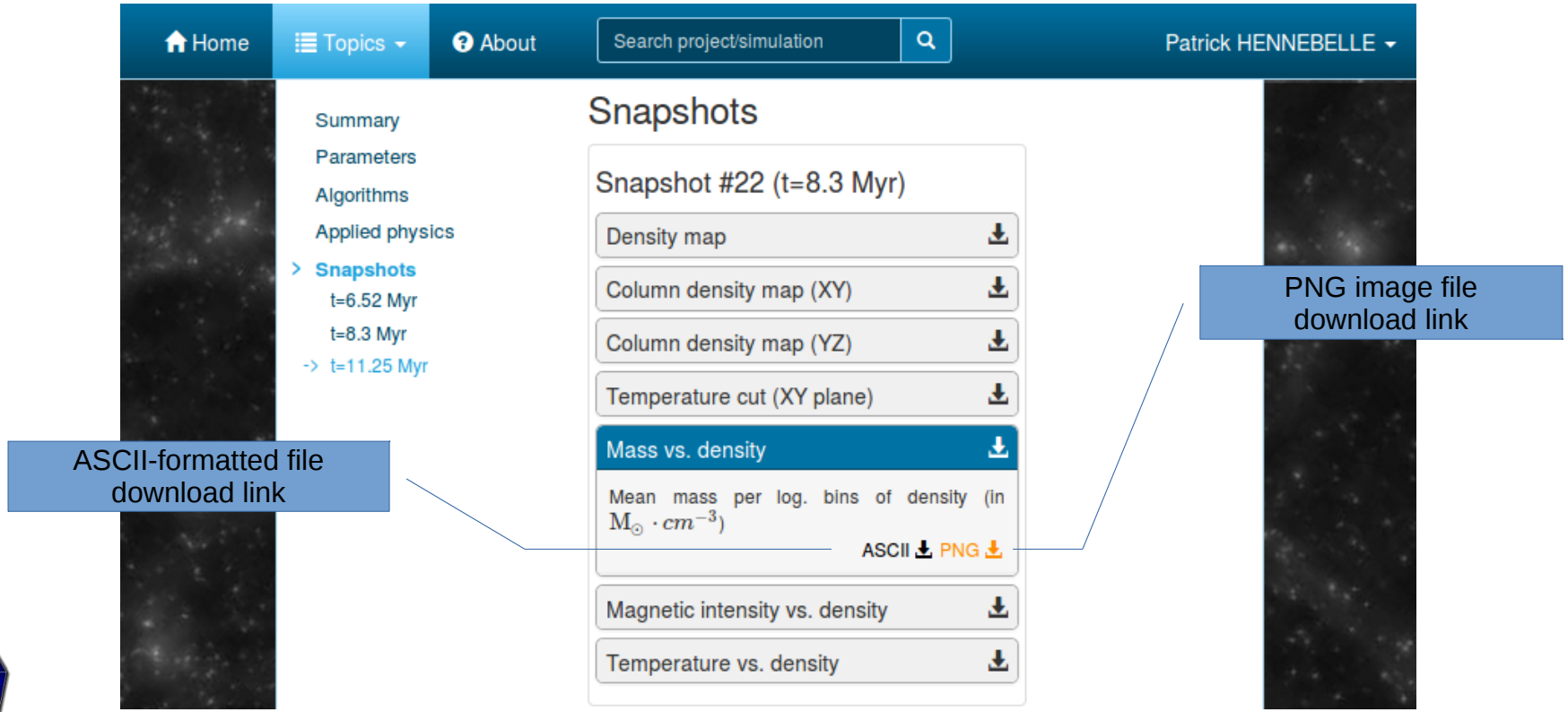
  - Database import report,



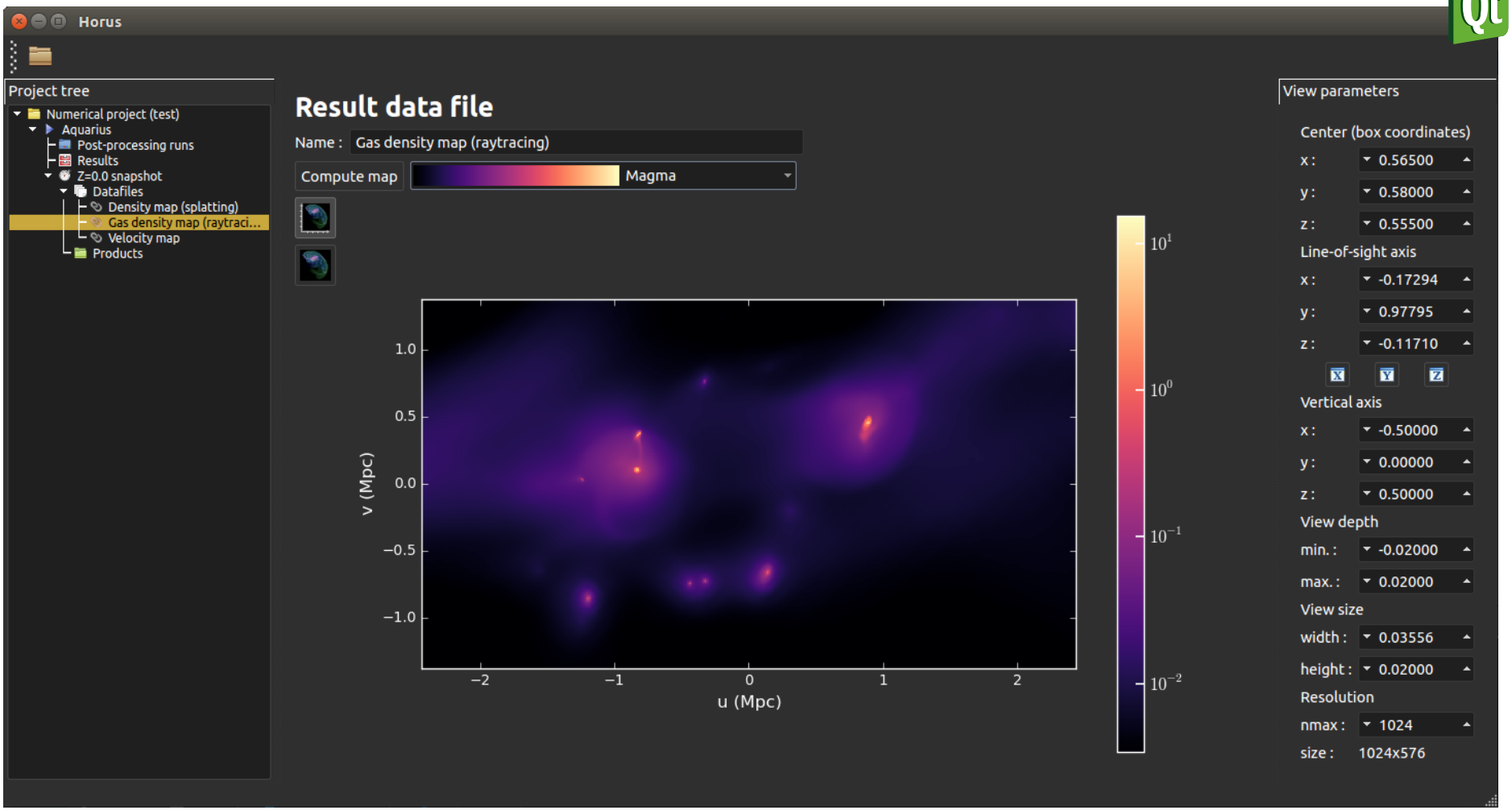
Massive data import from Horus

Data import from « Galactica archive » files

- Example : project import
  - **Horus** exported file upload (*.tar.gz containing JSON metadata + attached datafiles),
  - Database import preview,
  - Project full deployment in the Galactica database with a single click.



Horus GUI (PyQt4)



Galactica preview

Galactica preview

FRIG project (Démo)

Summary
> **Available simulations**
-> Run #6 (Zoom #7)

Summary

This project aims at describing self-consistently the formation of molecular clouds starting from the very diffuse atomic interstellar medium.

A flow of warm neutral medium (of densities of the order of 1 cm^{-3}) is arbitrary imposed (either as boundary or as initial conditions). Under the influence, first of cooling and ram pressure and then later of gravity, the gas undergoes a series of contraction reaching quickly a densities in the range of 10^2 cm^{-3} to 10^4 cm^{-3}. Then, in a second step gravity takes over and triggers the formation of dense cores which collapse and form stars.
The aim of these runs is to study the formation of molecular clouds from the warm atomic neutral medium (related reference Hennebelle et al. L43 A&A 486, 2008). Starting the simulation with WNM only, a converging flow is imposed from the left and from the right. The converging flow has a velocity equal to few times the sound speed of the WNM on top of which fluctuations have been superimposed. The magnetic field is initially uniform. The simulations includes atomic cooling and gravity. After a few million years, dense gas develops and eventually collapses.

In this project the following items can be found:

- values of the run parameters (e.g. strengths of the incoming flow, magnetic intensity at the boundary);
- statistics of the snapshots (as mass in the box, velocity dispersion) for 5 density thresholds and 5 column density thresholds (all numbers are calculated for the cells above these thresholds);
- various images of each snapshot (as density cut, temperature cut, column density);
- possibility to extract 2-dimensional maps from the snapshots and download the corresponding data;
- the results of clump extraction for various density thresholds, which include the statistics of the clumps (e.g. position, mass), clump images, possibility to extract and download 3-dimensional cubes of data.

The simulations have been performed with the RAMSES-MHD code (Teyssier 2002, A&A, 385, 337, Fromang et al., A&A, 457, 371). This is a mesh refinement code, implying that it can increase locally the spatial resolution by adding new cells in the computation. It uses the Godunov method and constraint transport method to maintain the divergence of the magnetic field equal to zero.

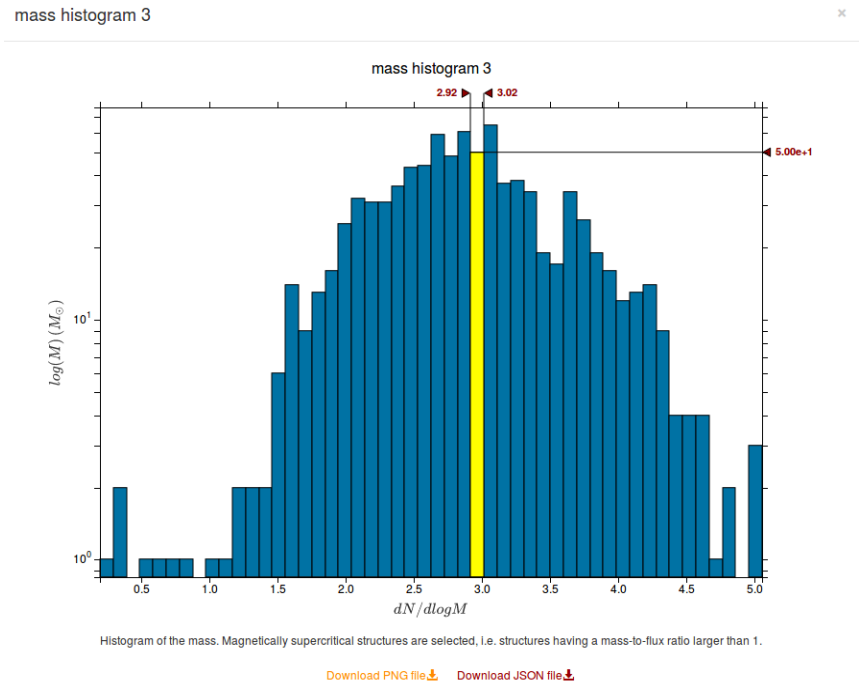
Available simulations

Run #6 (Zoom #7)

Run #6 (zoom #7)

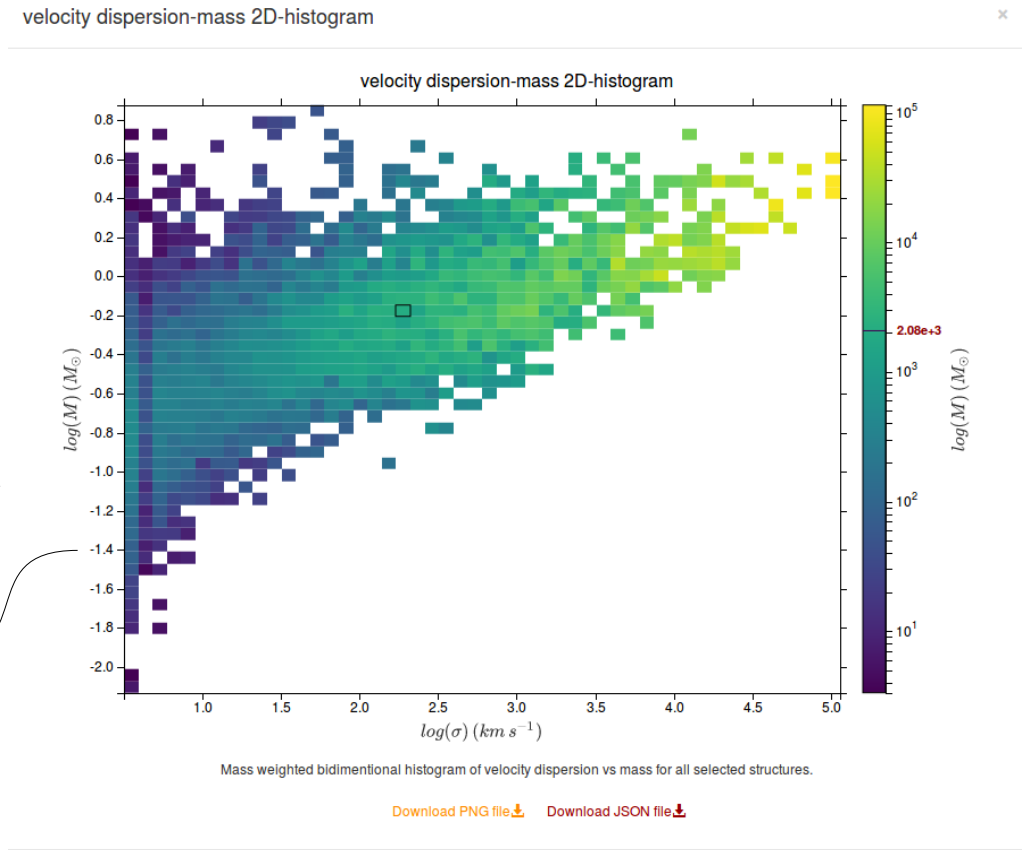
This run considered as "fiducial" has an effective numerical resolution equal to 1024^3 grid cells implying that the size of the smallest cell is about 0.05 pc. The magnetic field in the run and the velocity of the incoming flow are about 5 μG initially (but get amplified in the dense regions) and 18 $km.s^{-1}$ (about twice the sound speed of the warm neutral phase).

HTML-embedded plot using D3JS



D3JS-generated plot

Data-Driven Documents



MathJax integration

MathJax (https://www.mathjax.org/)

LaTex mathematical formula rendering engine (Javacript)

Summary

```
<p>This run is identical to the <a href="/db/STAR_FORM/COLL_FLOW/FIDUCIAL/">"fiducial" run</a> except that the magnetic field is not
considered. Although this is certainly not fully realistic, this allows to study the difference between the magnetized and non-magnetized
runs. The velocity of the incoming flow is about 18 km.s$^{-1}$ and the magnetic field intensity is 5 $\mu G$.
</p>
<p>Maxwell + Poisson + conservation equations :<br>
        \begin{eqnarray}
\nabla \cdot {\bf E} &=& \frac{\rho}{\epsilon_0} \nonumber \\
\nabla  \cdot {\bf B} &=& 0 \nonumber \\
\nabla  \times {\bf E} &=& - \frac{\partial \bf{B}}{\partial t} \nonumber \\
\nabla  \times {\bf B} &=& \mu_{0}{\bf J} + \mu_{0}\epsilon_{0}\frac{\partial {\bf E}}{\partial t} \nonumber \\
\Delta \Phi &=& 4 \pi G \rho \nonumber \\
\frac{\partial \rho}{\partial t} + \nabla \cdot ( \rho {\bf v} ) &=& 0 \nonumber \\
\frac{\partial ( \rho {\bf v} )}{\partial t} + \nabla \cdot ( \rho {\bf v} \times {\bf v} ) + \nabla P &=& - \rho \nabla \Phi \nonumber \\
\frac{\partial e}{\partial t} + \nabla \cdot ( ( e + P ) {\bf v} ) &=& -\rho {\bf v} \cdot \nabla \Phi \nonumber \\
\end{eqnarray}
</p>
```

MathJax integration

Hydrodynamical

Summary
Parameters
Algorithms
Applied phy…
Snapshots

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Maxwell + Poisson + conservation equations :

$$
\begin{aligned}
\nabla \cdot \mathbf{E} &= \frac{\rho}{\epsilon_0} \\
\nabla \cdot \mathbf{B} &= 0 \\
\nabla \times \mathbf{E} &= -\frac{\partial \mathbf{B}}{\partial t} \\
\nabla \times \mathbf{B} &= \mu_0 \mathbf{J} + \mu_0 \epsilon_0 \frac{\partial \mathbf{E}}{\partial t} \\
\Delta \Phi &= 4\pi G \rho \\
\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) &= 0 \\
\frac{\partial (\rho \mathbf{v})}{\partial t} + \nabla \cdot (\rho \mathbf{v} \times \mathbf{v}) + \nabla P &= -\rho \nabla \Phi \\
\frac{\partial e}{\partial t} + \nabla \cdot ((e + P)\mathbf{v}) &= -\rho \mathbf{v} \cdot \nabla \Phi
\end{aligned}
$$

Object catalog search form

Gas clump catalog

Gas clump catalog (1000 gas clump objects)

Search filters

Set custom search filters to get your own gas clump subset.

Field	Unit	Range		Min.	Mean	Max.	Std dev.
x	pc	85.062	160.786	85.063	120.139	160.786	9.398
y	pc	81.703	179.932	81.703	125.221	179.931	21.424
z	pc	475.565	524.939	475.565	500.138	524.939	10.686
mass	$M_\odot$	154.591	312.839	3.478	23.288	415.153	36.755
Mach number	year	1.149	65.384	1.150	6.787	65.383	6.722

Show 10 results. Sort by mass in descending order.

Search

Matching gas clump objects (from #1 to #10) total: 15 1 2 Next >

Id	data	x (pc)	y (pc)	z (pc)	Vx (km·s^{-1})	Vy (km·s^{-1})	Vz (km·s^{-1})	Bx (μG)	By (μG)	Bz (μG)	mass ($M_\odot$)	Mach number (year)	Mean density (cm^{-3})
433		121.261636	91.849396	522.946765	7.348302	6.269845	-8.942960	-34.846606	-30.228226	-20.284440	306.296834	20.364663	819084.130884
698		121.016476	91.956830	521.328851	3.388084	2.483125	-12.323844	-142.875361	-81.904641	-38.387619	295.037627	28.461312	925304.088369
197		121.301052	133.770963	502.400027	4.172585	4.522596	-7.689792	-4.861375	-43.687804	-206.818369	264.277486	15.789045	2964930.201531
340					4098	-1.515494	-14.978375	56.230397	-92.292502	-30.423011	256.753235	31.519099	2631802.744069
125					7866	7.887752	12.689819	616.651696	153.904790	409.624362	256.516219	21.366143	2224983.286133
201					2069	0.235002	-2.657135	229.561244	-25.651715	-175.915842	249.030341	12.549808	550245.956674
741		118.304722	124.810584	487.115812	2.172452	-4.867065	1.254081	19.153011	26.586855	-21.156760	223.690546	32.104093	5594642.961254

Ray-traced mass-weighted gas density map

“On-demand” post-processed data job requests (1)

Data post-processing form

Frontend (e.g. gas density map), for authenticated users only.

job request

Gas clump catalog : item 197

Ray-traced mass-weighted gas density map

Ray-traced mass-weighted density map of the gascontent displayed in log scale (values are computed in cm^{-3} unit). The map can be projected either along the x, y or z axis of the simulation box.

center (x-axis)*	0.121301	map center coordinate along x axis
center (y-axis)*	0.133771	map center coordinate along y axis
center (z-axis)*	0.5024	map center coordinate along z axis
map size*	0.1	map size in (box unit)
Projection axis*	z	ray-traced map projection axis

Submit job request

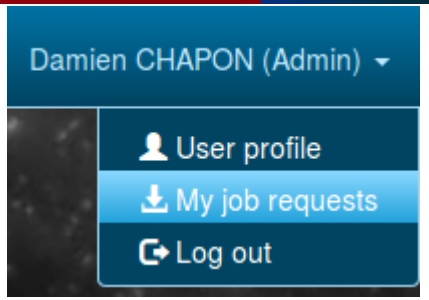
Go to top

OPEN DATA

“On-demand” post-processed data job requests (1)

User job requests

- Raw data post-processing (backend)
  - Job request sent to the Terminus server instance hosting the data.
  - Async. notifications via a RabbitMQ messaging server.



My job requests

Job requests :

Job request #7 [2017-04-26 18:12:51] — Submitted

Job request #6 [2017-04-26 18:09:13] — Submitted

Service title	Ray-traced mass-weighted gas density map
Job creation date	2017-04-26 18:08:59

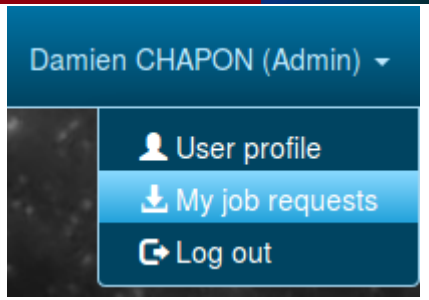
Target	
Category	Star formation
Project	FRIG project (Démo)
Experiment	Run #6 (Zoom #7)
Product	Gas clump catalog (Snapshot #249)
Object	Gas clump #197

Parameters	
center (x-axis)	0.1213
center (y-axis)	0.1337
center (z-axis)	0.5024
map size	0.15
Projection axis	y

“On-demand” post-processed data job requests (2)

User job requests

- Raw data post-processing (backend)
  - Job request sent to the Terminus server instance hosting the data.
  - Async. notifications via a RabbitMQ messaging server.



My job requests

Job requests :

Job request #4 [2017-06-23 16:56:50] — Pending execution

Service title	Ray-traced mass-weighted gas density map
Job creation date	2017-06-23 16:56:50

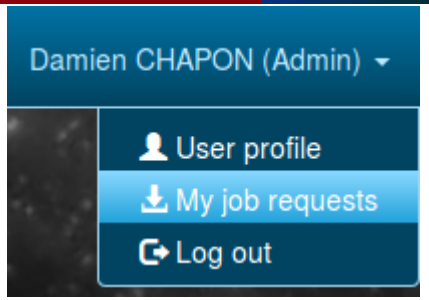
Target	
Category	Star formation
Project	Large scale simulation project
Experiment	Probe 3 (high-res)
Product	Gas clump catalog (Snapshot #86)
Object	Gas clump #2019

Parameters	
center (x-axis)	0.573041
center (y-axis)	0.849783
center (z-axis)	0.518265
map size	0.15
Projection axis	y

“On-demand” post-processed data job requests (3)

User job requests

- Raw data post-processing (backend)
  - Job request sent to the Terminus server instance hosting the data.
  - Async. notifications via a RabbitMQ messaging server.



My job requests

Job requests :

Job request #4 [2017-06-23 16:56:50] — Published

Service title	Ray-traced mass-weighted gas density map
Job creation date	2017-06-23 16:56:50

Target	
Category	Star formation
Project	Large scale simulation project
Experiment	Probe 3 (high-res)
Product	Gas clump catalog (Snapshot #86)
Object	Gas clump #2019

Parameters	
center (x-axis)	0.573041
center (y-axis)	0.849783
center (z-axis)	0.518265
map size	0.15
Projection axis	y

Download data

Email notification

Galactica database FAQ

New astrophysical simulation database : Galactica

- Integration of building block technologies :

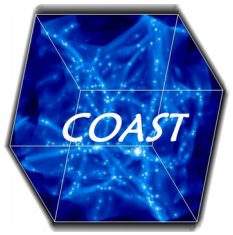

- Where ?
  - http://www.galactica-simulations.eu
- For whom ?
  - **Editors** : COAST group members and associated collaborators, and more...
  - **Data access**: Astronomers, numerical scientists, even general public.

- When ?
  - Publication : in prep. (2019)
- What kind of data/processing library ?
  - Unlimited type of post-processed data : 2D maps, plots, catalog subset, spectra, 3D extracted datacube, etc.
  - Plug-in system : interfaces nicely with any data post-processing library, for any simulation data format.

Conclusions

A software suite designed and developed by the COAST group for astrophysicists

- **Galactica** :cross-domain multi-project collaborative platform to publish and share astrophysical simulations : http://www.galactica-simulations.eu,
- **Terminus** : distributed data processing across Europe as Galactica services
- **Horus** : post-processing GUI to feed the database,
- Publication : 2019,
- Share your data !
- Ongoing and future work
  - Online interactive data selection/visualisation component (D3JS, leaflets.js, …),
  - Plugin implementations (Terminus services),
  - Horus GUI import functionalities
  - Make available several numerical projects in star formation and cosmology.



Thank you for your attention…

Questions ?

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